Quantum Circuit Design Optimization

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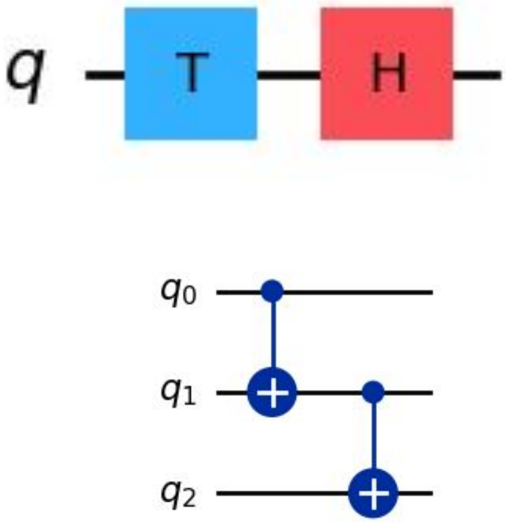
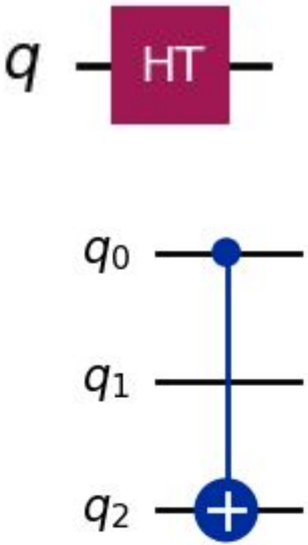
Optimization Methods

- Gate Fusion and Simplification
- Gate Decomposition
- Resource-Constrained Optimization
- Machine Learning Optimization for Circuit Design
- Variational Techniques

Gate Fusion and Simplification

Combining multiple gates into fewer gates.

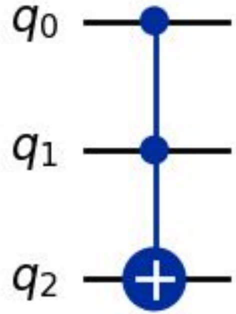


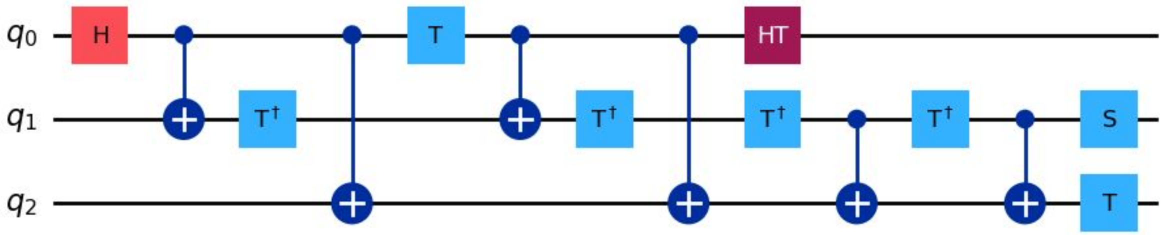


Gate Decomposition

Breaking down complex gates into simpler gates

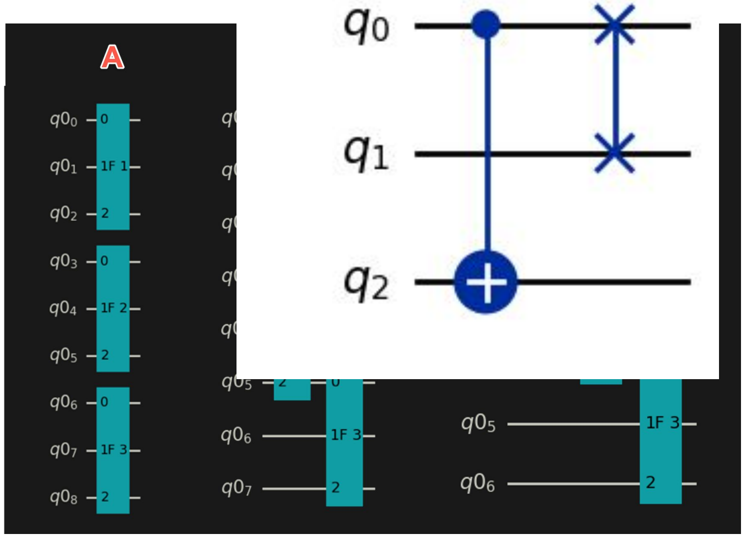
$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

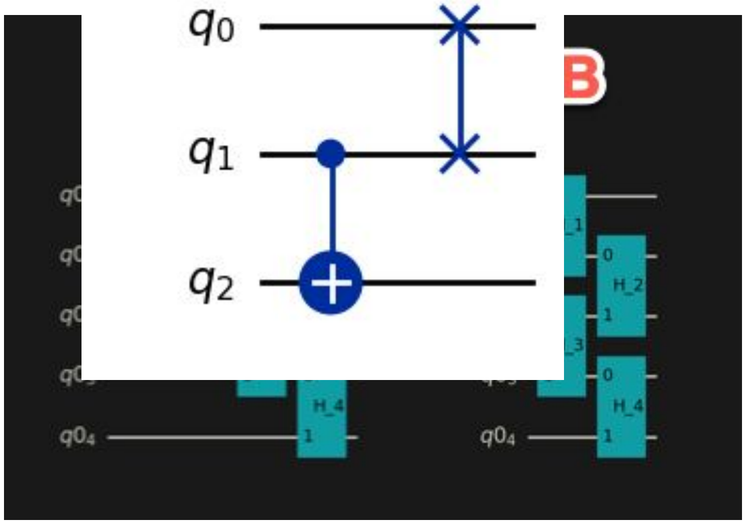




Resource-Constrained Optimization

Optimizing use of available resources





Why do we want to optimize?

- Reduce resource (#gates; depth)
- Minimize error (NISQ)
- Decrease execution time

DQN for Quantum Circuit Design

- Employ machine learni ... uit configurations, enhanc
- Process:
  - Environment: Define t ... are performed.
  - Agent: Develops a stra ... tes.
  - Rewards: Set rewards
- $Q(s,a) \leftarrow Q(s,a) + c$
- Where Q(s,a) is the qua ... y is the discount factor.

Model-Free Deep Recurrent Q-Network Reinforcen
Quantum Circuit Architectures Design

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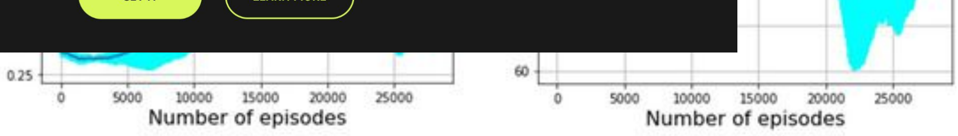
Quantum Rep. **2022**, *4*(4), 380-389; https://doi.org/10.3390/quantum4040027

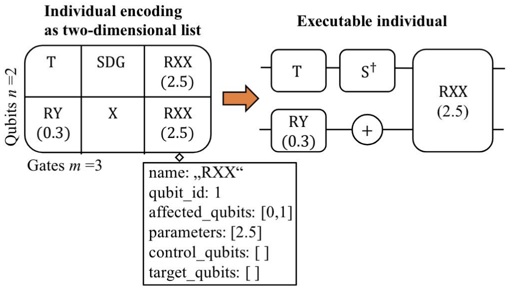
Submission received: 31 August 2022 / Revised: 16 September 2022 / Accepted: 19 September 2022 / Published: 21 September 2022



(a) (b)

GA for Quantum Circuit Design (Cont.)

- Genetic Algorithms: Use principles of natural selection to find optimal quantum circuits.
- Process:
  - Population: Start with a diverse population of random circuit designs.
  - Fitness Evaluation: Evaluate each circuit based on its performance (e.g., operational cost, fidelity).
  - Selection and Reproduction: Select the best-performing circuits to "breed" new circuits by combining features of parent circuits.
  - Mutation: Introduce random changes to new circuits to explore a broader design space.
- $\text{Fitness}(C) = \frac{1}{\text{Cost}(C)+\lambda\times\text{Error}(C)}$
- Where Fitness(C) is the fitness of circuit C, Cost(C) represents the operational cost (like gate count or depth), Error(C) quantifies the error rate, and λ is a penalty coefficient.



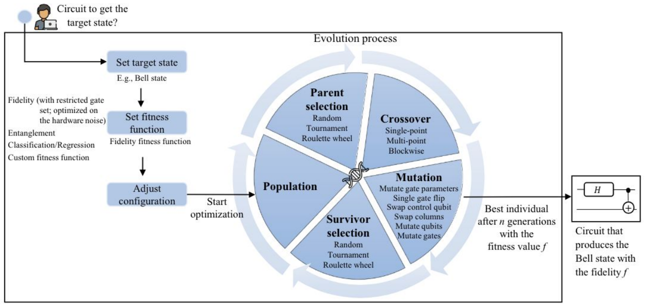
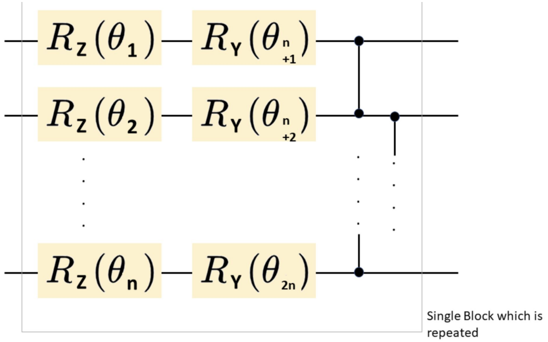
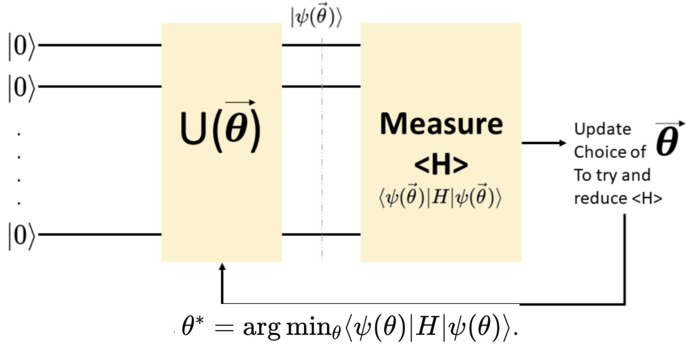


Figure 1: Optimization of quantum circuits in the GA4QCO framework.

Variational Quantum Eigensolver (VQE)

- A hybrid algorithm that uses both classical computers and quantum computers
- To find a set of quantum operations that prepares the lowest energy state of a close approximation to some target quantity.
- Iteratively explores different quantum states by adjusting θ, searching for the state that minimizes the Hamiltonian’s expectation value





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